Communication Networks course
Data Link Layer

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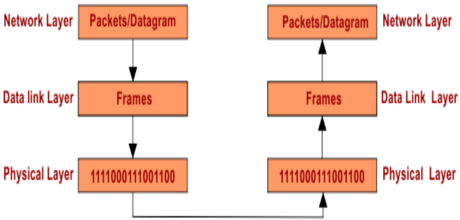
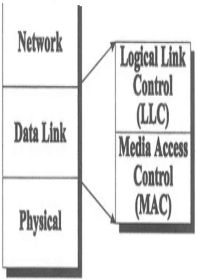
- Physical layer : transmission of bits.
- The data link layer (layer n° 2) : ensure the correction of transmitted bits.
- The data link layer (layer n° 2) : retrieves data packets from the network layer, wraps them in frames, sends them one by one to the physical layer.



The link layer must ensure :

- The delimitation of the exchanged data blocks ;
- Checking the integrity of received data ;
- The organization and control of the exchange.
- Shared channel access control

The link layer consists of two sub-layers : LLC (Logical Link Control) and MAC (Media Access Control)



Frame delimitation

Frame delimitation

- Asynchronous transmissions : start bits and stop bits frame the information bits
- Synchronous transmission : special information added for start and end of data
- Two methods :
  1. Character count
  2. Using Flags

Frame delimitation
Character counting

A field in the frame header is used to indicate the number of characters in the frame.

06	'S'	'U'	'P'	'E'	'R'	03	'L'	'E'	06	'C'	'O'	'U'	'R'	'S'

Frame delimitation
Character counting

A field in the frame header is used to indicate the number of characters in the frame.

Problem : if the value of the added field is modified during transmission ! !

The frame is delimited by a particular sequence of bits called flag.

Frame delimitation

Use of Flags

The frame is delimited by a particular sequence of bits called flag.

Problem : if the value of the flag appears in the data ! !

Frame delimitation

Use of Flags

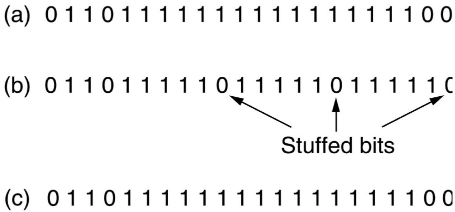
The frame is delimited by a particular sequence of bits called flag.

Problem : if the value of the flag appears in the data ! !

Solution : Binary Transparency (**bit stuffing)**

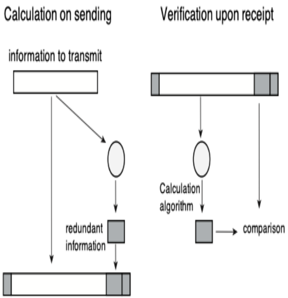
Frame delimitation
Using bit stuffing

Need for transparency bits ; For example, if the flag is byte 01111110, a "0" Transparency Bit is inserted after any sequence of five successive 1s in the frame.



Advantages : Synchronization always + frames of any size.

- Ensure that received data has not been altered during transmission
- Due to interference and distortion
- Exploit redundancy : Add control bits



Error Detection and Correction

Duplicate data

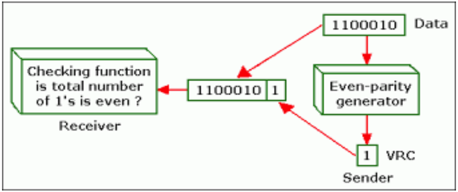
- Double message : difference : error ; equality : OK
- Problem : if the same error on both messages
- Message Triple : Correct by taking two identical copies ;
- Problem : if two different errors on two copies ;
- Problem : If the same error on two copies

- This is a code in which a bit (the parity bit) is added to the initial word to ensure parity.
- **Example :** Transmission of characters using a representation code (the 7-bit ASCII code).

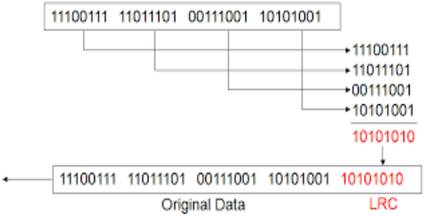
7 bits of data	(count of 1-bits)	8 bits including parity	
		even	odd
0000000	0	00000000	00000001
(Q) 1010001	3	10100011	10100010
(i) 1101001	4	11010010	11010011
1111111	7	11111111	11111110

- This code is able to detect all errors in odd number
- But it does not detect even number errors.
- It detects a parity error, but does not locate it.

To each character we add a bit (vertical redundancy bit or parity bit, VRC : Vertical Redundancy Check)



To each block of characters, we add an additional check field (LRC : Longitudinal Redundancy Check)



The data block is laid out in a matrix form $(k = a \bullet b)$. Parity is applied to each row and each column. We get a matrix $(a + 1, b + 1)$.

	H	E	L	L	O	LRC →
bit 0	0	1	0	0	1	0
bit 1	0	0	0	0	1	1
bit 2	0	1	1	1	1	0
bit 3	1	0	1	1	1	0
bit 4	0	0	0	0	0	0
bit 5	0	0	0	0	0	0
bit 6	1	1	1	1	1	1
VRC ↓	0	1	1	1	1	0

1001000	0	1000101	1	1001100	1	1001100	1	1001111	1	1000010	0
H		E		L		L		O		LRC	

- Most commonly used method for detecting group errors.
- Before transmission, control bits are added.
- If errors are detected on receive, retransmit.
- n bits $\rightarrow$ polynomial of degree $n-1$.
  - $1101 \rightarrow x^3 + x^2 + 1$
  - $110001 \rightarrow x^5 + x^4 + 1$
  - $11001011 \rightarrow x^7 + x^6 + x^3 + x + 1$

Use modulo 2 addition and subtraction (XOR)

	1	0	0	1	1	0	1	1
+	1	1	0	0	1	0	1	0
=	0	1	0	1	0	0	0	1

	1	1	1	1	0	0	0	0
-	1	0	1	0	0	1	1	0
=	0	1	0	1	0	1	1	0

- The source and the destination choose the same generator polynomial $G(x)$ of degree r.
- $M(x)$ polynomial corresponding to the original message.
- Multiply $M(x)$ by x^r, which is equivalent to adding r zeros to the end of the original message
- Perform the following division modulo 2 :

$$\frac{M(x)x^r}{G(x)} = Q(x) + R(x)$$

- The quotient $Q(x)$ is ignored. The remainder $R(x)$ (Checksum) contains r bits (degree of remainder $r-1$). We then perform the subtraction modulo 2 :

$$M(x).x^r - R(x) = T(x)$$

- $T(x)$ message ready to send

On reception, the following division is carried out :

$$\frac{T(x)}{G(x)}$$

- If the remainder $= 0$, there is no error
- If the remainder $\neq 0$, there is an error, so we must retransmit

By carefully choosing $G(x)$, we can detect any error on 1 bit, 2 consecutive bits, a sequence of n bits and beyond n bits with a very high probability.

1. Transmit the message 1011011 using the generator polynomial $G(x) = x^4 + x + 1$.
2. original message $= 1011011 \Rightarrow M(x) = x^6 + x^4 + x^3 + x^1 + 1$
3. $G(x) = x^4 + x + 1$
4. $M(x).x^4 = x^{10} + x^8 + x^7 + x^5 + x^4$
5. Compute $R(x)$ by Polynomial division

Polynomial division

$$
\begin{array}{ccccccccc|ccccccc}
x^{10} & + & x^8 & + & x^7 & + & x^5 & + & x^4 & x^4 & + & x & + & 1 \\
\cline{10-14}
x^{10} & + & x^7 & + & x^6 & & & & & x^6 & + & x^4 & + & x^2 \\
\cline{1-8}
x^8 & + & x^6 & + & x^5 & + & x^4 & & & & & & & \\
x^8 & + & x^5 & + & x^4 & & & & & & & & & \\
\cline{1-6}
x^6 & & & & & & & & & & & & & \\
x^6 & + & x^3 & + & x^2 & & & & & & & & & \\
\cline{1-6}
 & & x^3 & + & x^2 & & & & & & & & &
\end{array}
$$

$$R(x) = x^3 + x^2 = (1100)_2$$

The message to send $T(x) = M(x).x^r - R(x)$

$$T(x) = x^{10} + x^8 + x^7 + x^5 + x^4 - x^3 - x^2 = (10110111100)_2$$

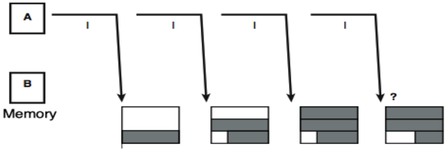
On reception, a similar calculation is performed on the received word, but here the remainder must be zero.

Otherwise, an error has occurred along the way.

- LRCC-8 : $x^8 + 1$
- LRCC-16 : $x^{16} + 1$
- CRC 12 : $x^{12} + x^{11} + x^3 + x^2 + x + 1$
- CRC 16 Forward : $x^{16} + x^{15} + x^2 + 1$
- CRC 16 Backward : $x^{16} + x^{14} + x + 1$
- CRC CITT Forward : $x^{16} + x^{12} + x^5 + 1$
- CRC CITT Backward : $x^{16} + x^{11} + x^4 + 1$

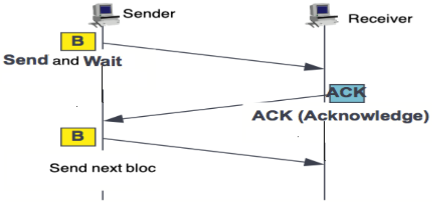
Flow control
Objective

- A : sender, B : receiver,
- If A produces faster than B consumes ⇒ B will be congested (saturated or overloaded)
- Flow control : send rhythm control
- Solution : Provide B with memory

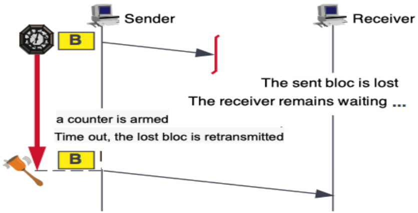


∀ memory size, it may be full

- A sends an information block and stops waiting for an acknowledgment.
- Upon receipt of the acknowledgment (ACK for Acknowledge), A sends the next block.



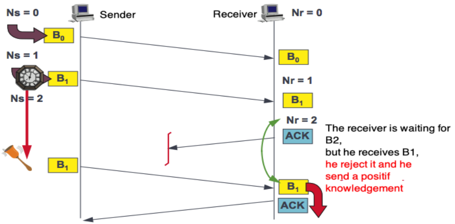
- In the event of an error, the received block is rejected by B (lost) and is not acknowledged.
- A then remains pending ! ?
- Solution : Armed a timer.
- At Time Out, if no ACK, A retransmits.



Flow control
Sent and Wait

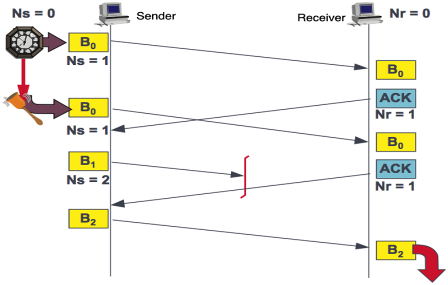
- What if ACK is lost ! ! ! ?
- A retransmits, B receives twice.
- Solution : A uses an Ns counter (Number sent) and B an Nr counter (Number to receive)
- Ns, Nr initialized to 0,

- A transmits Ns with the block,
- B compares with Nr.
- If $=$, valid block. If $\neq$,
- Block rejected and acknowledged if it matches a block already received.



If the consumption times are longer :

- A transmits B0,
- B treats B0 heavily then acknowledges,
- A retransmits B0 then receives the acknowledgement, and transmits B1,
- B receives the 2^{nd} B0 and acknowledges
- B1 lost
- A receives the acknowledgment of B0, it considers it of B1 and transmits B2
- B1 is not resent



- Solution : number the acknowledgments,

The waiting time for acknowledgments makes the send and wait method inefficient.

Flow control

Anticipation window

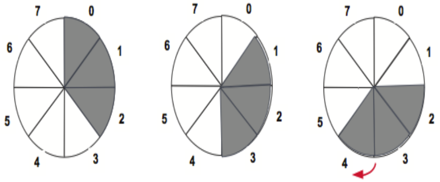
- Reduces waiting time for acknowledgments
- Anticipation : emit multiple blocks without waiting for ACKs
- Window of size W : ACK acknowledges W frames
- $r \leq Ns \leq r + W - 1$, r :the number of the next expected frame
- $W = 1$ in the case of a Send-and-Wait procedure.

Flow control

Anticipation window

To be able to retransmit erroneous frames :

- Transmitter : save unacknowledged frames in buffers
- Acknowledged frame : free the corresponding buffer
- Window *"sliding"*
- Example : frames numbered from 0 to 7, $W = 3$



Flow control

Anticipation window

- If receiver wants to suspend the exchange for a period,
- It sends a particular frame (Receiver not ready)
- Transmitter suspends until received (Receiver Ready)

- Link Layer Protocols,
- Implement previous techniques (frame delimitation, error correction and flow control)

- HDLC (High-level Data Link Control) developed by IBM and standardized by the ITU in 1976
- point-to-point and multipoint in full duplex,
- frames separated by flags of value 01111110 (7E)
- Three modes :
  1. Normal Response Mode (NRM) : secondary waits for an order from the primary to transmit.
  2. The secondary Asynchronous Response Mode (ARM) : sends without being prompted by the primary. Known as LAP (Link Access Protocol).
  3. The Asynchronous Balanced Mode (ABM) response mode : point-to-point link ; LAP-B (Link Access Protocol-Balanced). Currently the only mode used.

1. Information frames or **I** frames : ensure data transfer ;
2. Supervision frames or **S** (Supervisor) frames : ensure the transmission of supervision commands (acknowledgment of receipt, etc.),
3. Unnumbered frames or **U** (Unnumbered) frames : supervise the link (connection, disconnection).

Data management procedures
HDLC Procedure (Frame Structure)

8 bit	8 bit	8 bit	n bit	16 bit	8 bit
flag	address	control	information	FCS	flag

Data management procedures
HDLC Procedure (Frame Structure)

- Pennant (flag) : 01111110
  - delimits frames.
  - frame synchronization : constantly search for the flag ;
  - a flag : closing and opening ;
  - transparency inserts a 0 after every five consecutive 1's other than the flags appear.

- Address field : command or response frame. For ABM, preset values : 11000000, 10000000, 11110000 1110000).
- Control field : frame type + parameters.
- FCS (Frame Check Sequence) : CRC16 V.41 $(x^{16} + x^{12} + x^5 + 1)$.

	1	2	3	4	5	6	7	8
Information	0	Ns			P/F	Nr		
Supervision	1	0	S	S	P/F	Nr		
Unnumbered	1	1	M	M	P/F	M	M	M

- Ns : transmitted frame number,
- Nr : next frame number expected (acknowledgment in the data),
- P/F (Poll/Final) := 1 $\Rightarrow$ immediate response solicits.

S-frame :

S	S	Command	Meaning
0	0	RR (Receiver Ready)	Station is ready to receive frame Nr number and accuse positively reception frames up to (Nr - 1)
0	1	RNR (Receiver not Ready)	Station is not ready to receive frames but and positively acknowledges t reception of frames until (Nr - 1)

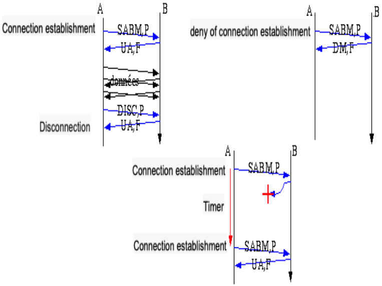
S-frame :

S	S	Command	Meaning
1	0	REJ (Reject)	Station rejects frames from number Nr. The issuer is obliged retransmit (P/F = 1)
1	1	SREJ (Reject)	=REJ but only for frame number Nr.

U frame :

Frame	Command	Meaning
11111100	SABM	Set ABM request establishment in ABM mode
11110000	DM	Disconnect Mode indicates that the station is located at offline
11001010	DISC	Disconnect release link
11000110	UA	Unnumbered Acknowledge indicates the reception and acceptance of a unnumbered order

Data management procedures
HDLC procedure (example of exchanges)



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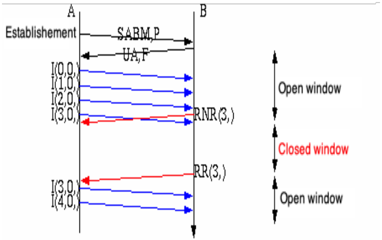

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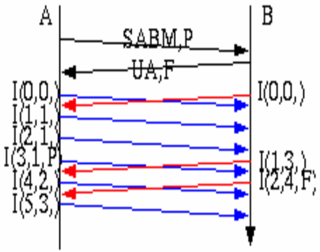

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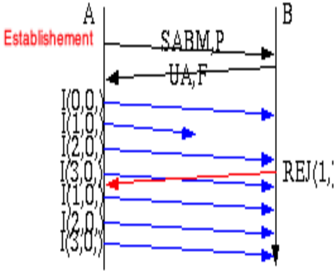

MAC sublayer

Addressing

- Physical address (hard level) (MAC address)
- Format defined by IEEE : 48 bits
- Universal device addressing 24-bit
- : constructor, 24-bit serial number

Adresse constructeur 24 bits	Adresse carte 24 bits

Adresse MAC (6 octets)

- LAN : machines share the same bandwidth
- Arbitration needed : access method
- CSMA/CD, Token ring

MAC sublayer

Media Access Techniques (CSMA/CD)

- Carrier Sense Multiple Access with Collision Detection (often referred to as Ethernet)
- Random method,
- Broadcast Network
- Listen before sending,
- If busy : wait for release
- If free : send and continue listening (duration min)
- If no problem : continue sending the frame
- If problem (collision) : wait random time then return
- Video

MAC sublayer

Media Access Techniques (CSMA/CD)